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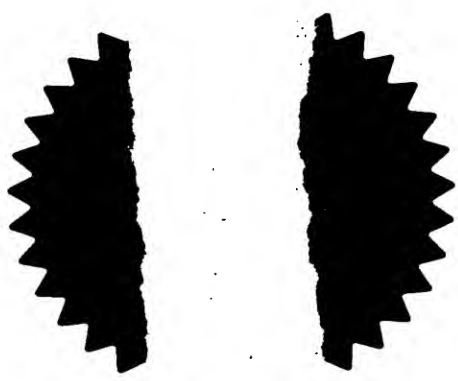
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1. Your reference

85.78688/001

2. Patent application number  
(The Patent Office will fill in this part)

0303055.8

3. Full name, address and postcode of the  
or of each applicant (underline all surnames)Micromass Limited  
Atlas Park  
Simonsway  
Manchester  
M22 5PP  
United Kingdom11FEB03 15:40:25-1 000027  
P01/75 0.00-0303055.8

Patents ADP number (if you know it)

If the applicant is a corporate body, give  
country/state of incorporation

UK

4. Title of the invention

Mass Spectrometer

5. Name of your agent (if you have one)

Frank B. Dehn &amp; Co.

"Address for service" in the United Kingdom  
to which all correspondence should be sent  
(including the postcode)179 Queen Victoria Street  
London  
EC4V 4EL

Patents ADP number (if you know it)

166001

6. If you are declaring priority from one or more  
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each application number

Country

Priority application number  
(if you know it)Date of filing  
(day / month / year)

GB

0214898.9

27/06/02

7. If this application is divided or otherwise  
derived from an earlier UK application,  
give the number and the filing date of  
the earlier application

Number of earlier application

Date of filing  
(day / month / year)8. Is a statement of inventorship and of right  
to grant of a patent required in support of  
this request? (Answer 'Yes' if:

Yes

- a) any applicant named in part 3 is not an inventor, or
  - b) there is an inventor who is not named as an applicant, or
  - c) any named applicant is a corporate body.
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SECTION 30 (1977 ACT) APPLICATION FILED  
6996102003



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Continuation sheets of this form

Description

Claim(s)

Abstract

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10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

Request for substantive examination (Patents Form 10/77)

Any other documents (please specify)

11. I/We request the grant of a patent on the basis of this application.

Signature

Date 11 February 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

P.M. Jeffrey  
01273 244200

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By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of:-

MICROMASS UK LIMITED  
Incorporated in the United Kingdom  
Atlas Park  
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United Kingdom

ADP No. 07649676002





## Travelling Wave Ion Guide as a Mobility Analyser

### Introduction to RF ion Guides

Radio Frequency (RF) ion guides are commonly used for confining and transporting ions. All such ion guides use an arrangement of electrodes with an RF voltage applied between neighbouring electrodes such as to produce a pseudo-potential well or valley. This pseudo-potential well can be arranged to confine ions, and may be used to transport ions by acting as an ion guide. Its use as an ion guide is well known, and can be very efficient.

The RF ion guide can still function efficiently as an ion guide even at quite high pressures, where ions are likely to undergo frequent collisions with residual gas molecules. The collisions with gas molecules may cause the ion to scatter and lose energy, but the pseudo potential well generated by the RF ion guide still acts to confine the ions. In this respect the RF ion guide has an advantage over the "guide wire" type of ion guide, in which a DC voltage is applied to a central wire running down the centre of a conducting tube. In this arrangement ions are held in orbit around the central guide wire. However, in the "guide wire" type of ion guide, if ions undergo many collisions with gas molecules they will lose energy and will eventually collapse into the central guide wire and be lost.

As a consequence of their ability to transport ions at relatively high pressures, RF ion guides are the preferred type of ion guide for a number of applications in mass spectrometry apparatus. In particular they are used in "gas collision cells" in which relatively low energy ions (i.e. ions with energies between 10 and 1000 eV) undergo multiple collisions with gas molecules to induce ion fragmentation or decomposition. Similarly, they are used in "gas reaction cells" in which low energy ions (i.e. ions with energies between 0.1 eV and 10 eV) undergo collisions with gas molecules to form adjunct ions.

RF ion guides are also used to transport ions through chambers at intermediate pressures (0.001 - 10 mbar), for example from an ion source in a chamber at high pressure (e.g. an atmospheric pressure ion source) to a mass analyser in a chamber at very low pressure. Such mass analysers include the quadrupole ion trap, the quadrupole mass filter, the time-of-flight mass spectrometer, the magnetic sector mass spectrometer, and the Fourier Transform Ion Cyclotron Resonance mass spectrometer (FTICR). In both instances ions can be efficiently transported despite undergoing many collisions with gas molecules causing the ions to be scattered and to lose energy.

It is well known that ion transit times through RF only ion guides, collision cells and reaction cells, when operated at sufficiently high gas pressure, can be long due to reduction of axial ion energy by collisions with the gas. It is also known that the continued presence or absence of an incoming ion beam, and any surface charging leading to axial potential barriers, can further affect the transit time.

As has been already mentioned, when an ion collides with a gas molecule it may get scattered and lose kinetic energy. If the ion undergoes a large number of collisions,

perhaps more than 100 collisions, the ion will lose all its forward kinetic energy. The ions will now have a mean energy equal to that of the surrounding gas molecules. They will now appear to move randomly within the gas due to continuing random collisions with gas molecules. Hence, under some operating conditions, ions being transported through an RF ion guide at an intermediate gas pressure will lose all their forward motion. Under these conditions the ions will never emerge from the exit of the ion guide.

In practice ions may still continue to move forwards for other reasons. It is normally assumed that ions may continue to move forwards due to the bulk movement of gas (a gas dynamic "wind") blowing the ions through the ion guide, or due to space charge caused by continual ingress of ions into the device (electrostatic repulsion from ions arriving from behind) effectively pushing the ions through the ion guide (1). Without these influences it is known that under certain conditions ions can, in effect, come to a standstill in the ion guide and not emerge at the exit.

A known means for driving ions through an RF ion guide at intermediate pressures is the use of an axial electric field. To ensure the ions emerge, or simply to reduce their transit time, it has become current practice to apply an axial voltage gradient along the ion guide. The axial electric field may be applied in a number of ways. For example, axial electric fields may be applied to ion guides using multipole rod sets by the use of segmented rods with a DC voltage between successive rods (2), by the use of inclined or tapered rods (3), or by the use of resistive rods with a DC voltage gradient along their length (3). Axial fields may be applied to ion guides using stacked ring sets by applying a DC voltage to successive rings (4) or groups of rings (5). Axial fields may also be applied by the use of additional electrodes, usually in the form of cylinders, external to the ion guide such that some of this axial field penetrates into the ion guide itself (3). In all these cases the axial electric field causes the ions to accelerate forwards after each collision with a gas molecule. A very weak field, in the region of 0.1 to 1 volt/cm, is adequate for pressures between 0.001 and 0.01 millibar. At higher pressures higher field strengths can be used.

In the pressure region above 0.001 millibar ions in an axial field will attain velocities according to their ion mobility. When such drift tubes are used in conjunction with a pulsed ion source then separation of species according to their ion mobility is achieved. The output of such a mobility spectrometer may be coupled to mass spectrometer to achieve charge state separation (6) to improve signal to noise.

### Swept Mobility Extraction Guide

The new invention is a variation on the Travelling Wave Ion Guide (TWIG) (7) which entails superimposing a repeating pattern of electrical potentials along the length of the ion guide such as to form a periodic waveform, and causing the waveform to travel along the ion guide in the direction in which it is required to move the ions, and at the velocity at which it is required to move the ions.

The travelling wave device requires that an RF ion guide, such as a multipole rod set or stacked ring set, is segmented in the axial direction such that independent transient DC potentials can be applied to each segment, superimposed on top of the RF confining voltage and any constant DC offset voltage, whereby the DC potentials are changed temporally to generate a travelling wave in the axial direction.

At any instant in time a voltage gradient would be generated between segments to push or pull the ions in a certain direction. As the ions move in the required direction so would the voltage gradient. The individual DC voltages on each of the segments would be programmed to create a required waveform. Furthermore, the individual DC voltages on each of the segments would be programmed to change in synchronism such that the waveform would be maintained but shifted in the direction in which it is required to move the ions.

Consider now a stacked ring ion tunnel device (at a pressure such that an ion traversing its length undergoes many collisions) filled with ions such as may be generated by an electrospray or MALDI ion source. If the end plates of the tunnel have a slight positive voltage with respect to all the central plates then ions will be trapped in the device unable to surmount the potential barrier. After a certain time equilibrium will be reached where ions of all masses and mobilities are distributed along the length of the device [Figure 1]. If a voltage is then applied to the first electrode in the tunnel adjacent to one of the end plates the ions will be pushed down the device [Figure 2] by the local field variation according to the equation:

$$V_{drift} = K * E(x) \quad (\text{Equation 1})$$

where  $V_{drift}$  is the drift velocity of the ion  $K$  its mobility and  $E(x)$  the electric field caused by the applied voltage. The electric field caused by the applied voltage rapidly decays to a negligible value just a few electrode spacings. The voltage is then rapidly switched to the next electrode and an ion that had enough time to drift at least one electrode spacing will experience the same force and move again. Those ions of low mobility may not have time to drift far enough to see the influence of the voltage when it switches to the next electrode and will be left behind. The voltage travels down the device from electrode to electrode "sweeping" those ions with a high enough mobility to follow it. The device acts as a high pass filter in that ions with mobilities above a chosen value can be ejected from the tunnel whilst the rest remain trapped in the device [Figures 3 & 4]. The sweep time of the device  $T_{sweep}$  may be then reduced to select a slightly lower mobility cut off ejecting those ions which have mobilities between the two cut off points. By gradually reducing the sweep time a complete mobility "scan" may be built up until the device is empty. Another way to scan the device is to increase the voltage progressively with each sweep collecting ions of ever decreasing mobility in the same way. Note that from equation (1) doubling the voltage will double the velocity of an ion. The resolution of the device is in part determined by the size of the sweep ( $T_{sweep}$ ) time or Voltage increment. The smaller the step between adjacent sweeps the greater the resolution of the device.

The mode of operation described above builds up a mobility spectrum by a series of high pass experiments. Isolation of a particular range of mobilities i.e. bandpass operation may be achieved by employing a two stage device. Firstly ions with mobility  $> X$  are passed through the device into a second empty stage [Figure 5]. The

travelling wave may be reversed sweeping ions back into the first stage [Figure 6]. This reverse sweep may be faster (or of a higher voltage) so that the required mobility range is left behind in the second stage [Figure 7].

The resolution of the travelling wave device has been modelled to include the effect of diffusion of ions. Diffusion effects degrade the resolution of conventional drift tube IMS devices there being a fundamental equation showing a relationship between the drift tube length and the applied axial voltage drop (8):-

$$\frac{|X|}{L} = \frac{0.173}{\sqrt{V}} \quad (\text{Equation 2})$$

where mod X is the spatial spread due to diffusion, L the drift tube length and V the applied axial voltage drop. To increase the resolving power of the mobility spectrometers longer drift tubes and higher voltages are traditionally employed. An advantage of the current invention is that only a relatively low voltage is required i.e. that which is applied to a single element, typically this would be 10 Volts or so at a pressure of ~ 2mBar. The SMEG device has been modelled as a series of elements with the voltage resident on each element for a certain time. Diffusion is introduced as a random scattering component over the time of residence of the voltage on an element. The program used to predict the behaviour of the device is shown in figure 8. The result shown in figure 9 predicts the complete separation of Gravidin S and Leucine encephalin. This result is for a SMEG with 100 elements and a voltage of 7 volts on each plate. This result is comparable with the performance one would expect from a single pass drift tube of similar dimensions.

Further improvements in resolution may be achieved by sweeping the ions backwards and forwards through the same volume. This has the effect of increasing the effective length of the device without actually increasing its physical dimensions. Ions may be purged from the swept volume after the passage of the travelling wave by switching the RF off allowing ions to diffuse out of that portion of the device. After the desired number of passes of the same volume the ions may be allowed out of the device for further analysis.

### Advantages over prior art

#### 1) High Duty Cycle:

The new device can operate at 100% duty cycle as it is able to eject only those ions of desired mobility while storing the rest for further analysis. This is in contrast to a Field Asymmetric Ion Mobility Spectrometer (FAIMS) which is a scanning device whereby ions that are not transmitted are lost to the walls of the device.

#### 2) Flexible timescale of ion ejection

The drift tube type works by admitting a short pulse of ions (known as the gate pulse) and allowing them to disperse in an electric field according to their mobility. By trapping ions prior to the drift tube they can be accumulated while the drift tube is dispersing ions and duty cycles approaching 100% may be achieved. The separation

is generally on the millisecond timescale so subsequent experiments must be amenable to this to be able to take advantage of the duty cycle. In the case of the charge state separation device the quadrupole must be scanned in synchronisation with the output of the drift tube. This can cause significant losses in ion transmission as ions that enter the quadrupole with a stable trajectory may find themselves unstable part way through the quad and so be lost. With the current invention the quadrupole can be set to a discrete mass to charge transmission window to match the desired mobility range ejected by the device. This means that the desired ions are stable in the quadrupole all through the device. The equivalent to a scanning experiment can be performed piecewise with no loss in duty cycle as unejected ions are still stored by the device.

3) No Gate pulse required:

To obtain high duty cycle with a drift tube type of mobility spectrometer when using continuous ion sources requires the use of a trapping stage. Ions are then admitted to the Drift tube using gate pulses which are narrow compared to drift times of ions. A spectrometer that disperses on the millisecond timescale therefore requires a gate pulse of the order of microseconds to achieve the best resolution. The use of such gate pulses result in mobility discrimination at the input to the device leading to lower sensitivity and skewed spectra. The SMEG device has no need for a narrow gate pulse as the device can be filled with a longer pulse and so avoids these problems.

4) Large voltages not required:

As can be seen from equation 1 a limiting factor comes from the spatial spread of the ions caused by diffusion. Drift tube devices employ large voltage drops across them to minimise this problem. The SMEG only requires a small voltage as the ions are localised at the active plate at any moment in time. Ten volts in a SMEG equates to ~1000 Volts on a drift tube with a 100 element device.

5) Folded multipass geometry:

As ions may be send backwards and forwards within the SMEG device greater resolution can be achieved in a more compact device than in a drift tube of similar dimensions. More passes of the device (in the second less populated region) lead to greater isolation of the desired species.



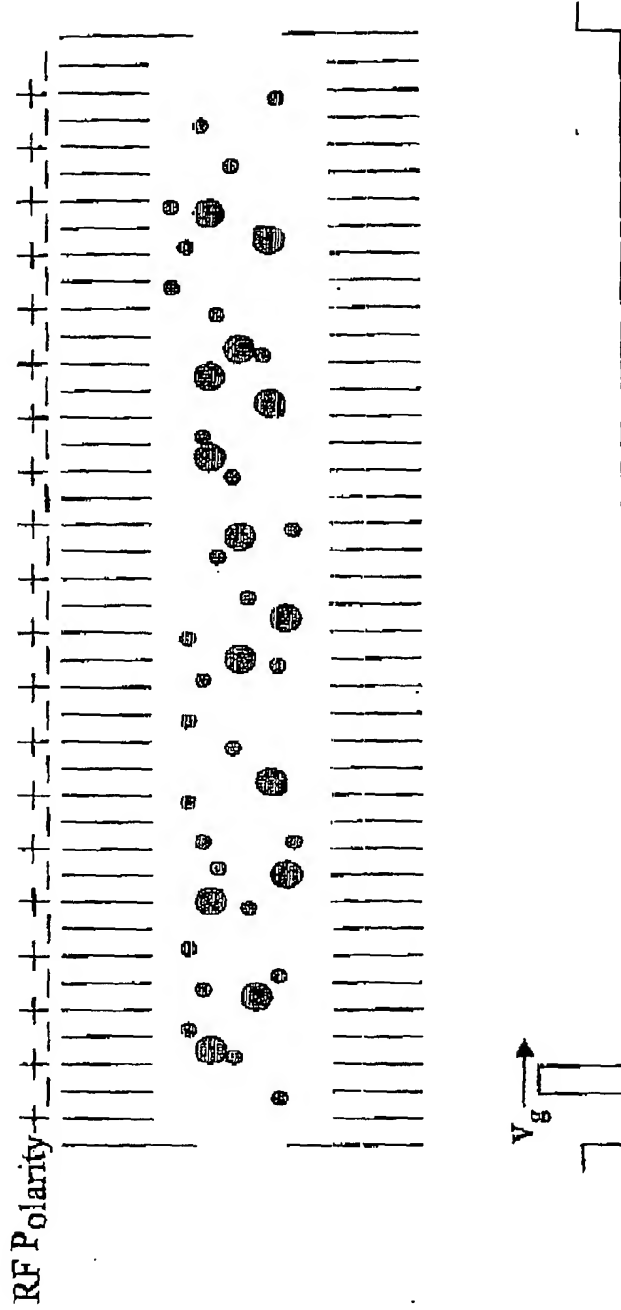


Figure 2. Travelling wave begins at one end of device

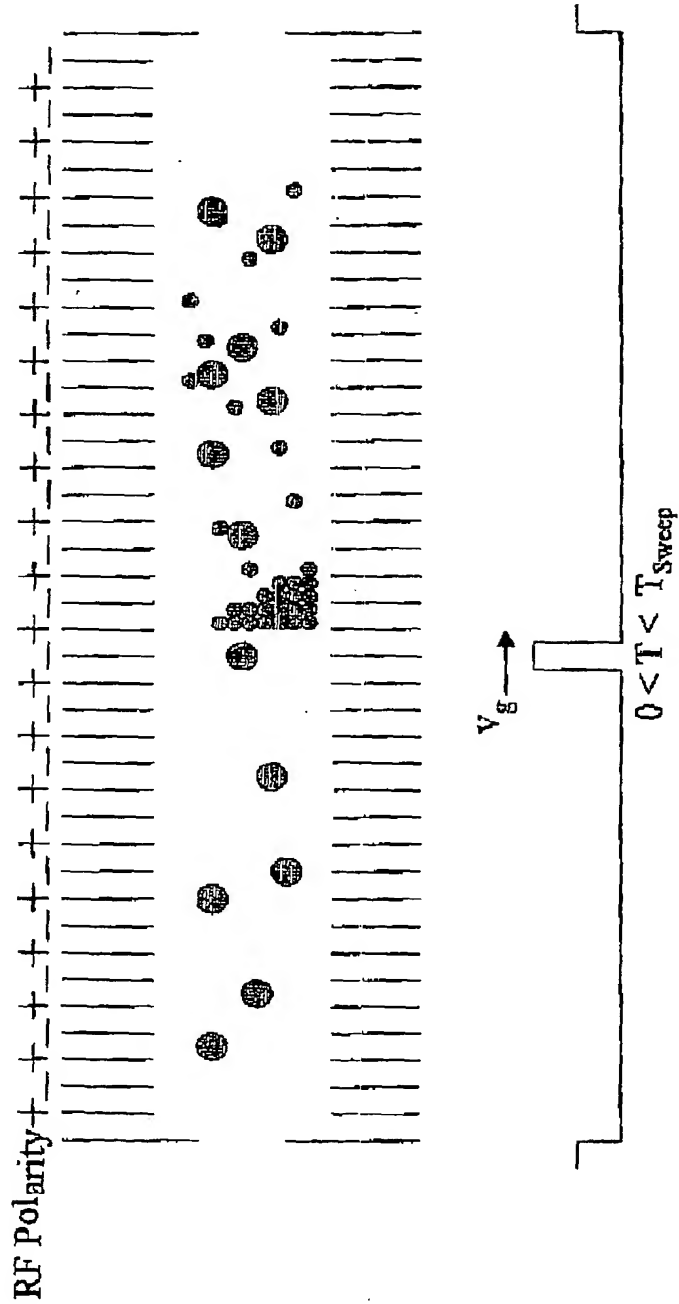


Figure 3. Travelling wave sweeping high mobility ions



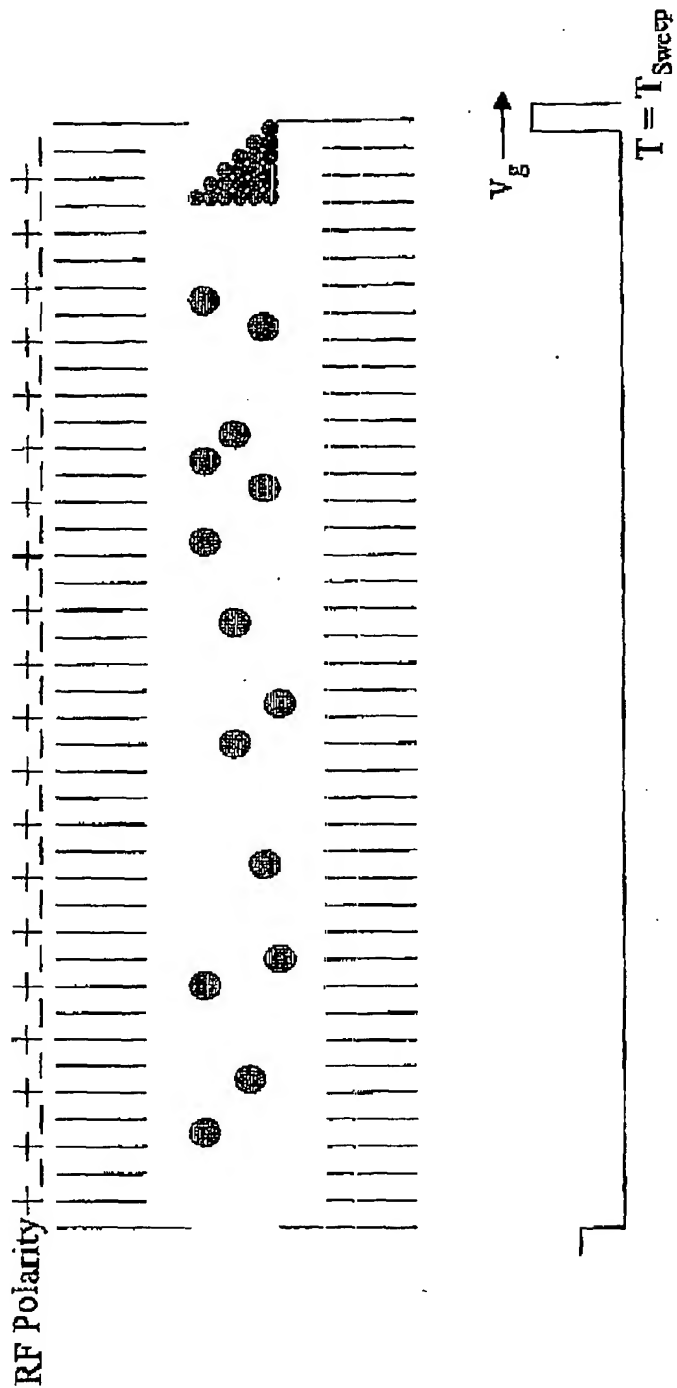


Figure 4. All high mobility ions swept and ejected from device

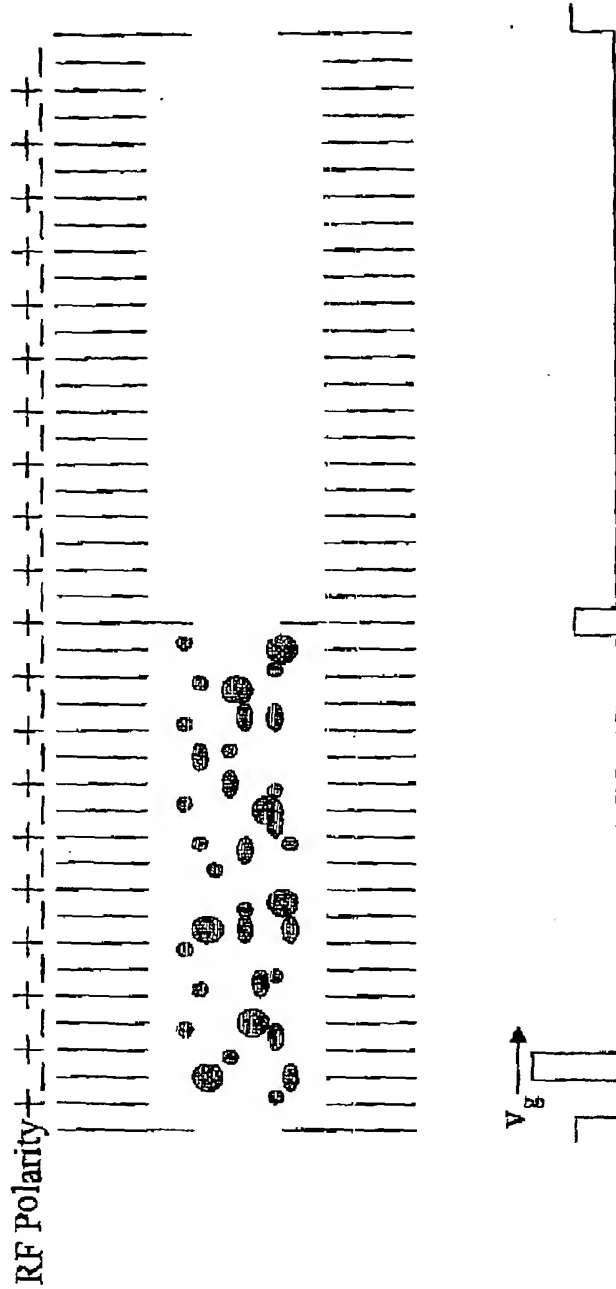


Figure 5. Split device at equilibrium

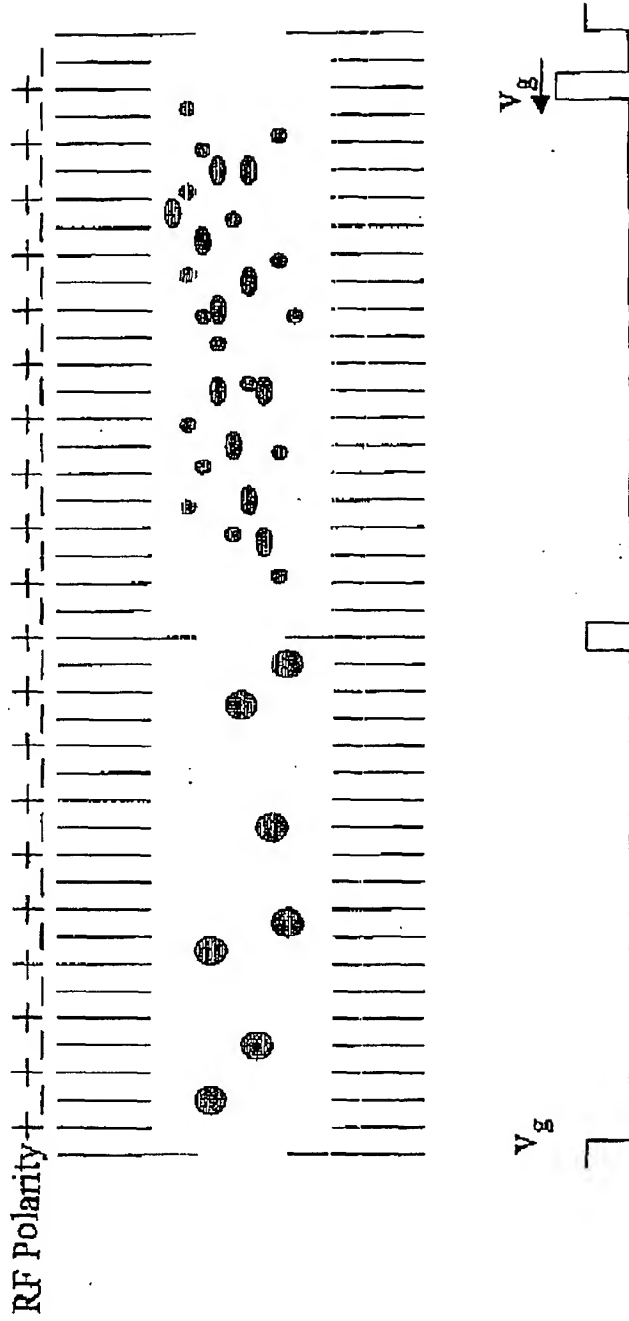


Figure 6. Higher mobility ions swept into second stage of device, wave direction reversed and intensity  $V_g$  reduced.

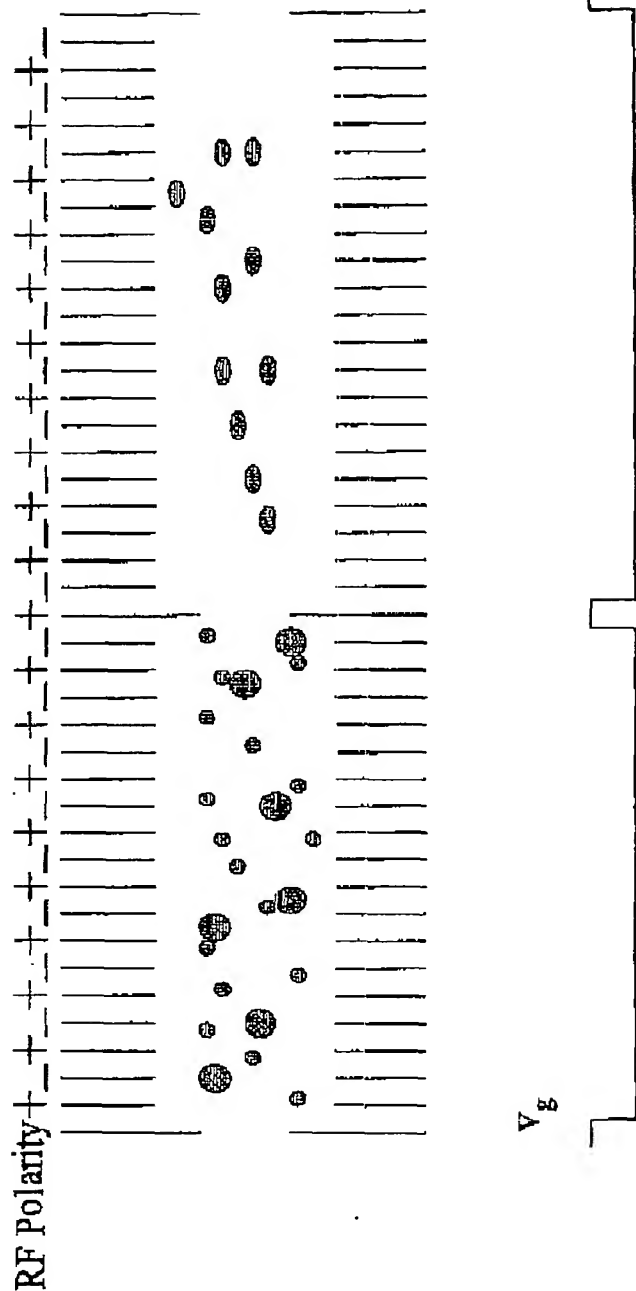


Figure 7. Intermediate mobility left behind in second stage (bandpass operation).

$$\begin{aligned}
 L &:= 1.5 \cdot 10^{-3} & V_p &:= 3.5 & T &:= 1.55 \cdot 10^{-5} & K &:= 6.6 \cdot 10^{-2} & N_{el} &:= 100 & N_{ion} &:= 1000 \\
 x_0 &:= 1.5L & c &:= K \cdot V_p \cdot 3.142 \frac{T}{4L} & sig &:= \sqrt{2 \cdot K \cdot \frac{T}{42.465}} & a &:= \frac{3.142}{2L} & SwT &:= N_{el} \cdot T \\
 c &= 1.875 \times 10^{-3} & a &= 1.047 \times 10^3 & x_0 &= 2.25 \times 10^{-3} & sig &= 2.195 \times 10^{-4} & SwT &= 1.55 \times 10^{-3}
 \end{aligned}$$

```

f2(x0) := for i ∈ 1..Nel
  deltadist ← norm(i, 0, sig)
  x0 ← [ -7a * arccos( ( -exp(2·c·a) * exp(2·c·a) * cos(x0a) + 1 + cos(x0a) ) /
    ( -exp(2·c·a) + exp(2·c·a) * cos(x0a) - 1 - cos(x0a) ) ) ] - L + ∑ deltadist if x0 ≥ 0
  x0 otherwise
x0

```

$$f2(x_0) = -1.598 \times 10^{-4}$$

```

M := for j ∈ 0..Nion - 1
  m_j ← f2(x0)
m

```

$$M_0 = 1.33 \times 10^{-3} \quad M_{10} = -6.346 \times 10^{-4} \quad M_{20} = 1.113 \times 10^{-3}$$

$$M_{30} = 1.07 \times 10^{-3} \quad M_{40} = 1.12 \times 10^{-3}$$

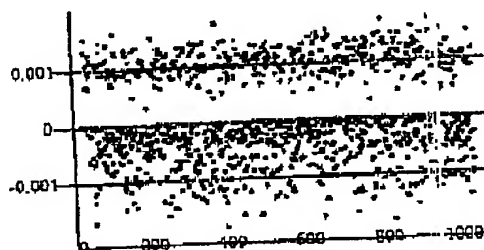
Position relative to Nth element

```

f3(M) := cnt ← 0
for k ∈ 0..Nion - 1
  cnt ← cnt + 1 if M_k ≥ 0
OP ← cnt / 100
Nion
OP

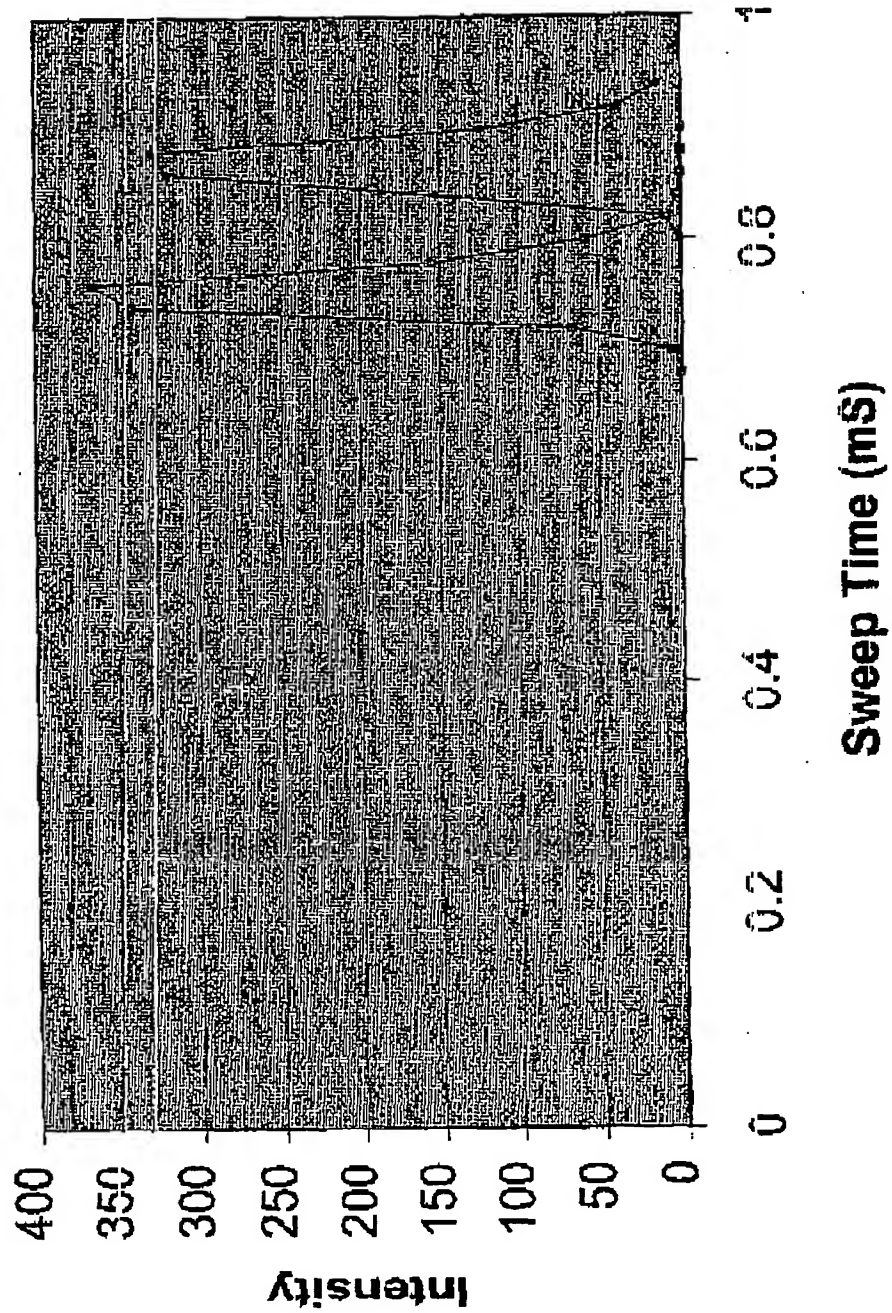
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$$f3(M) = 35.2$$



M

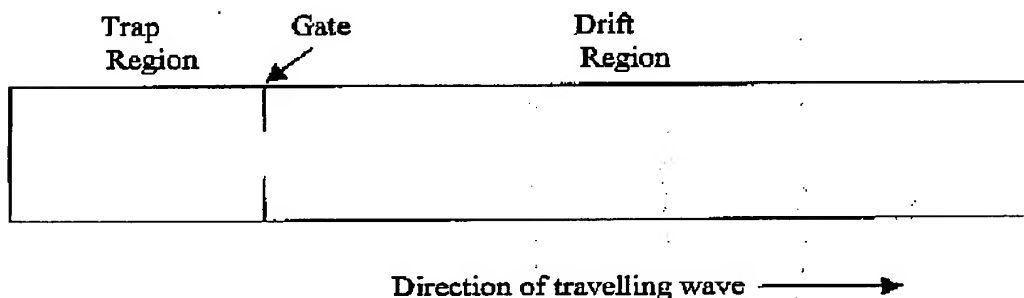
Figure 8

**LeuEnk V's Gram-s Mobilty (100 elememts, Vp = 7)***Figure 9*

## Travelling Wave Ion Guide Mobility Modes

A constantly running travelling wave can be used to separate ion species according to their mobility if implemented in a 'drift region' of sufficient gas pressure. The wave amplitude and velocity can be tailored such that ions do not 'surf' on a single pulse along the drift region but roll over the top of the pulses, thereby receiving a succession of nudges leading to an overall drift in the wave direction. The transit time of an ion through the drift region will therefore be dependent on its mobility.

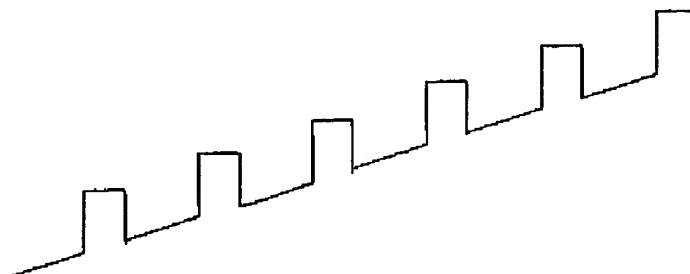
The device would be constructed of a TWIG type device for the drift region (either a stack of plates or segmented multipole) and an ion trapping region upstream of the drift region with a gate to periodically pulse bunches of ions from the trap to the drift region.



1 The simplest mode of operation is with a travelling wave having a periodic pulse of constant amplitude and velocity.



2 Another mode of operation is to superimpose a reverse DC gradient on the travelling wave such that the field acts between pulses to move ions back to the gate. This will potentially enhance the separation characteristics of the device and could be used to prevent ions below a specific mobility from travelling with the wave and exiting the drift region.



3 In this mode of operation, the height of the pulse reduces along the drift region as the potential due to the axial gradient increases. Again this may enhance separation. Further, in this mode it is possible that ions of certain mobility will find "balance points" along the drift region where the movement caused by the travelling wave is counteracted by the reverse axial gradient. Ions of different mobility will find "balance points" at different positions along the device. By this means a 'static' mobility separation could be produced. Ions of similar mobility would collect in specific regions. These ions could be transmitted in a 'band-pass' operation.



This mode of operation does not necessarily require a gate since it can operate with a continuous ion beam. Furthermore, the DC axial field may be constant or variable with position. This may be achieved by applying potentials to the elements of the ion guide that increase either linearly or non-linearly. Alternatively, the amplitude of the travelling wave may decrease linearly or non-linearly as it progresses from the entry end to the exit end of the device. Of course both the DC axial field and amplitude of the travelling wave may change with position. In one particular arrangement the DC axial field may continuously increase from the entry end to the exit end whilst the amplitude of the travelling wave remains constant.

The DC axial gradient, the amplitude of the travelling wave and the velocity of the travelling wave may also change with time. Hence, ions of differing mobility may first be separated spatially along the length of the ion guide, and then moved along the ion guide to one end or the other. Ions may then be caused to leave the device in order of their mobility.

For example ions that have been separated may then be caused to move to the exit by either reducing the DC potential gradient or by increasing the amplitude of the travelling wave. These ions may also be moved to the exit end by reducing the velocity of the travelling wave, or by reducing the gas pressure. Ions may also be caused to move by changing a combination of these controls. In this example ions may then be caused to leave the device in order of their mobility, starting with ions of highest mobility.

Alternatively, the separated ions may be caused to move to the entrance end of the device either by increasing the DC potential gradient, by reducing the amplitude of the travelling wave, by increasing the velocity of the wave, or by increasing the gas pressure. Again a combination of these parameters may be changed to cause movement of the ions. In this example ions may then be caused to leave back through the ion entry end of the device in order of their mobility, starting with ions of lowest mobility.

4 The use of varying pulse amplitude, wave velocity, pressure and axial gradient during operation could be used to enhance the separation.



5 The Ion Mobility separator as described above may be used in isolation for the analysis of a substance by means of measurement of the mobility of its component parts. It may also be used in isolation for separation, collection and storage of components of a substance.

6 The Ion Mobility separator may also be used in combination with a mass spectrometer or tandem mass spectrometer. The combination with a mass spectrometer provides a means of analysis with greater specificity. It also provides a means of separation, collection and storage of component fractions of a substance, and therefore provides a means by which more components of a substance may be subsequently analysed in a mass spectrometer in greater detail.

7 A reversed axial voltage gradient could also be used with the SMEG device (MM 1159) to enhance separation by constantly returning ions not carried along completely by the travelling wave pulse to the entrance of the separation region.

## Travelling Wave Ion Guide Mobility Separation

A constantly running travelling wave was used to separate ion species according to their mobility. Ions were first collected in an ion tunnel arrangement consisting of a stack of 90 ring electrodes, each 0.5 mm thick and spaced apart by 1.0 mm. The central aperture in each ring was 5.0 mm diameter and the total length of the ion tunnel was 134 mm. A 2.1 MHz RF voltage was applied between neighbouring rings to confine the ion beam. Ions were retained in the ion tunnel by raising the DC potential at each end by approximately 5 volts. The pressure in the ion tunnel was about  $10^{-3}$  mbar.

Ions were continuously generated using an electrospray ion source and continuously directed into the ion tunnel. The DC potential at the exit end of the ion guide was periodically reduced to allow ions to leave the ion tunnel. Ions were repeatedly collected and stored for 11 msec and then released over a period of 26  $\mu$ sec. Ions leaving the ion tunnel were accelerated through a 3 volt potential difference, and then passed through a quadrupole rod set. The quadrupole was operating with only RF voltage applied to the rods so that it was not acting as a mass filter. The ions exiting the quadrupole rod set then entered the travelling wave ion guide.

The travelling wave ion guide (TWIG) device consisted of a similar ion tunnel to that used for collecting and storing ions. The tunnel arrangement consisted of a stack of 122 ring electrodes, each 0.5 mm thick and spaced apart by 1.0 mm. The central aperture within each ring was 5.0 mm diameter and the total length of ring stack was 182 mm. A 2.4 MHz RF voltage was applied between neighbouring rings to confine the ion beam. The pressure in the ion tunnel was about  $2 \times 10^{-2}$  mbar.

The travelling wave consisted of a regular periodic pulse of constant amplitude and velocity.



Direction of travelling wave  $\longrightarrow$

The travelling wave was generated by applying a DC voltage to a single ring electrode, and every subsequent ring displaced by nine rings along the ring stack. Hence, one wave-length ( $\lambda$ ) of the waveform consisted of one ring with raised DC potential followed by eight rings at a lower potential. Thus the wavelength ( $\lambda$ ) was equivalent to 9 rings, or 13.5 mm, and the total ion guide was equivalent to approximately  $13.5 \lambda$ . The travelling wave was generated by applying approximately 0.65 volts to each ring electrode for 5  $\mu$ sec before moving the applied voltage to the next ring. Thus the wave period or cycle time ( $t$ ) was 45  $\mu$ sec. This was repeated uniformly throughout the length of the travelling wave ion guide. Thus the wave velocity ( $v = \lambda/t$ ) was equal to a constant 300 m/sec.

At the exit of the travelling wave ion guide the ions passed through a second quadrupole rod set. This had both RF and DC supplies and could be tuned to transmit ions of just one  $m/z$  value. The ions were detected on a detector just after this second quadrupole rod set.

A mixture of Gramacidin-S (mol wt 1142 daltons) and Leucine Enkephalin (mol wt 555 daltons) was continuously introduced into the electrospray ion source. Singly charged protonated ions of Leucine Enkephalin ( $m/z$  556) and doubly charged protonated ions of Gramacidin-S ( $m/z$  572) were collected and stored in the first ion tunnel. These ions were periodically released and their transit times to the detector were recorded. The transit times were recorded on an oscilloscope and are shown in the attached figure. For each measurement the second quadrupole was tuned to just transmit either  $m/z$  556 for Leucine Enkephalin or  $m/z$  572 for Gramacidin-S. The oscilloscope recordings also show the "release pulse" indicating the time at which ions were released from the first ion tunnel.

The trace for Gramacidin-S (figure 1) shows that the peak arrival time for ions was about 2.2 msec after release from the first ion tunnel. The corresponding trace for Leucine Enkephalin (figure 2) shows the peak arrival time was about 3.1 msec after release from the ion tunnel. The timing cursors show the transit time for Gramacidin-S was 940  $\mu$ sec less than that for Leucine Enkephalin. This is in spite of the fact that the  $m/z$  value for Gramacidin-S (572) is marginally greater than that for Leucine Enkephalin (556), and that the Gramacidin-S molecule (mol wt 1142 daltons) is bigger than the Leucine Enkephalin molecule (mol wt 555 daltons). A shorter transit time for Gramacidin-S would be expected however since the  $m/z$  572 ion is doubly charged and experiences twice the force due to the electric field of the travelling wave than that experienced by the singly charged Leucine Enkephalin ion at  $m/z$  556. The doubly charged Gramacidin-S ion experienced twice the force, but not as much as twice the viscous drag since its cross sectional area is not twice that of Leucine Enkephalin. It might be expected their relative cross sectional areas are in the ratio approximately  $(1144/556)^{2/3}$  which is approximately 1.6. Hence the Gramacidin-S ion is more mobile than the Leucine Enkephalin ion in the presence of the same electric field and same high gas pressure, and therefore is less likely to slip over the tops of the waves in the travelling wave ion guide. As a result, the transit time for Gramacidin-S in the travelling wave ion guide is less than that for Leucine Enkephalin. In fact its overall transit time is less than that for Leucine Enkephalin despite the fact that the Leucine Enkephalin ions with the lower  $m/z$  value will travel slightly faster through the two quadrupoles.

This experiment demonstrates two ions with the same  $m/z$  values but with different charge states ( $z$  values) may be separated by the travelling wave ion mobility separator.

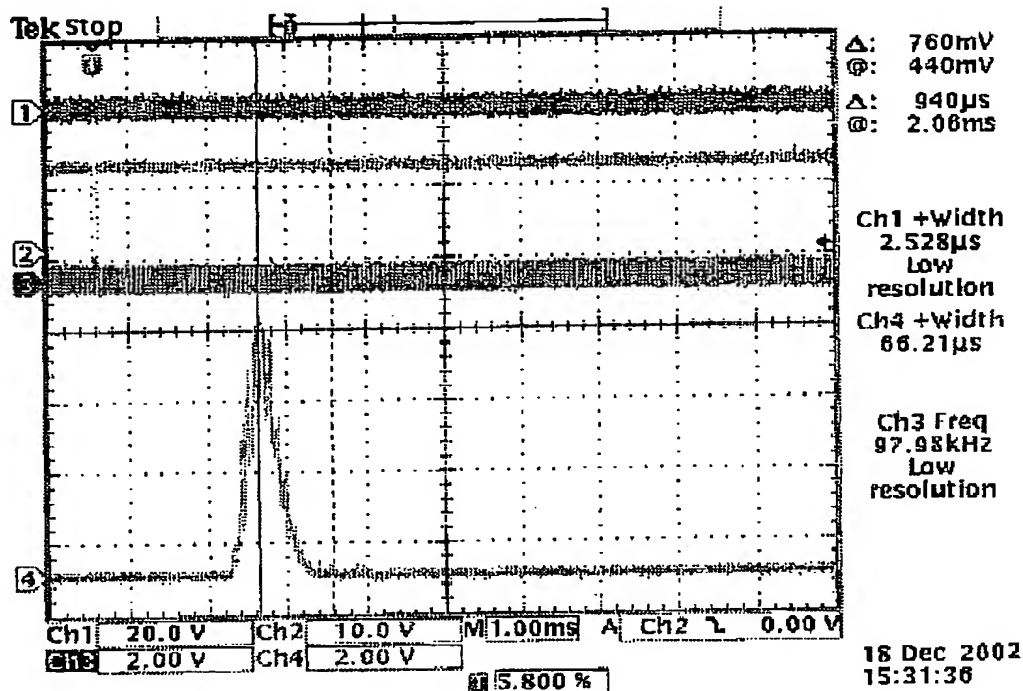


Figure 1: Transit time recorded for Gramacidin-S ( $m/z$  572)

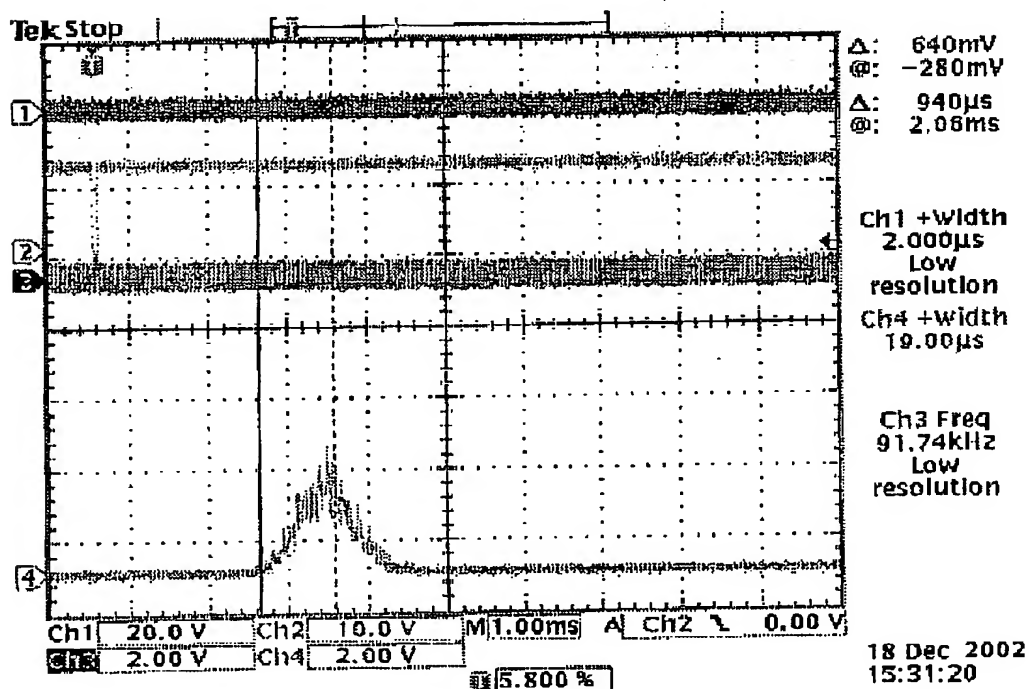


Figure 2: Transit time recorded for Leucine Enkephalin ( $m/z$  556)



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